Practical Limnology: A Primer Series

by John Hains – Clemson University

Chapter 1

Introduction: In this series, I will present topics in the field of limnology that are important to water quality, especially for Lake Keowee. The series will follow a logical order and each subsequent topic will build upon, or enhance, previous ones. In a sense, the series will be a detailed story of water and will use Lake Keowee and its watershed as the example.

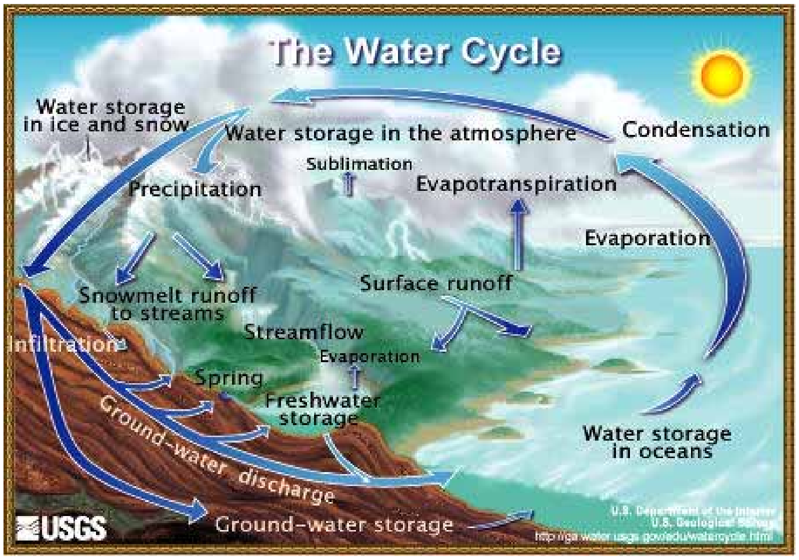
The field of limnology has been likened to 'inland oceanography' and a variety of other similes. It is the study of freshwater, whether in lakes or rivers, and encompasses every process in the watershed that affects both water quantity and water quality. In this sense, it is a field of 'ecosystem' science in that it involves interacting physical, chemical, and biological systems. The field of limnology much in common with other fields and employs them, such as: aquatic ecology, hydrology, geology, hydrodynamics, engineering, geochemistry, sedimentology, etc.

Lake Keowee is a complex system that is affected by many forces. The water in Lake Keowee is deposited as precipitation that is moved to this area by weather, powered by sunlight. The water in Lake Keowee moves in complex patterns that are determined by the type of forces on it and by the shape of the basin. The materials that are dissolved in the water or suspended as particles are moved with the water but each material may have its own unique source. The sources may be natural or man-influenced.

The flow of water through Lake Keowee and the motion of water within Lake Keowee are the product of many forces including the hydrologic cycle, the shape of the basin, the operation of Keowee Dam and of Jocassee Dam, and the operation of Oconee Nuclear Station. The supply and motion of the water are the most important single factor in understanding Lake Keowee and because these are physical processes, the place for this series to begin is with physical limnology. So we will.

The Hydrologic Cycle

Water is continually cycled through natural systems. Water for Lake Keowee mostly comes as discharge from the watershed that includes numerous tributary streams fed by runoff and groundwater, as well as Lake Jocassee and numerous smaller lakes. It arrives as water vapor and is deposited as precipitation. An excellent website in which to explore the hydrologic cycle is:
http://observe.arc.nasa.gov/nasa/earth/hydrocycle/hydro1.html



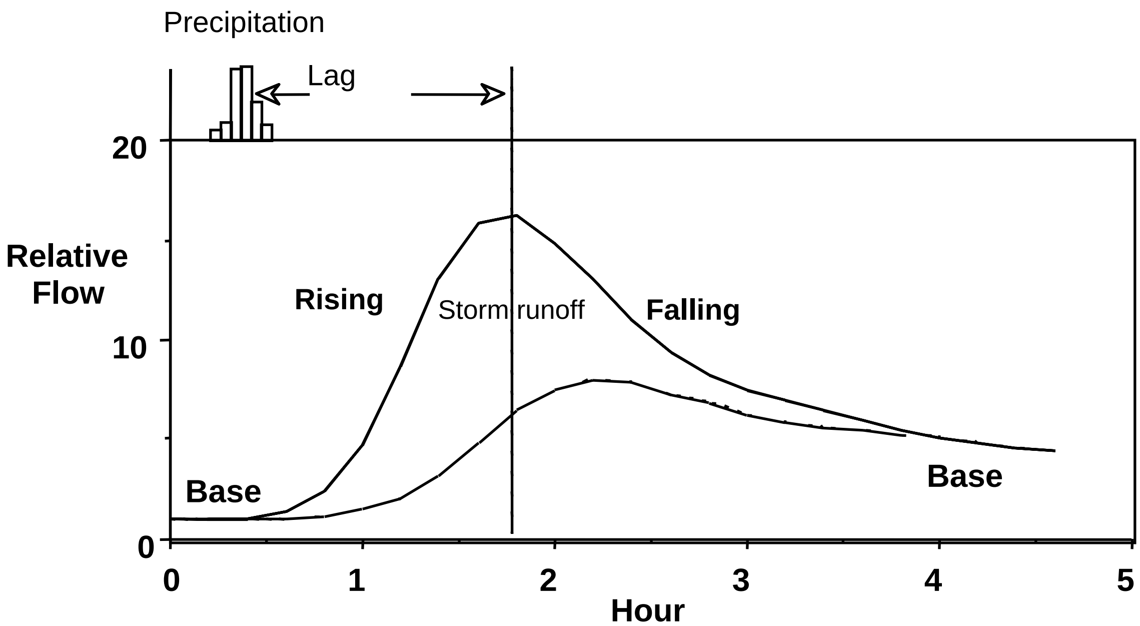
The above figure (from the USGS website) diagrams the hydrologic (water) cycle.

Water moves as it is evaporated from the land, streams, lakes, and ocean, and later precipitated over the Lake Keowee watershed. Much of the water in Lake Keowee originated in the Gulf of Mexico. In order to evaporate water, energy is required just as in the process of making steam. When the vapor condenses and is precipitated, energy is released just as in the thunderstorms we experience in the summer and fall. The energy required for the hydrologic cycle is almost entirely solar. Energy enters the system as sunlight, moves the water, and then energy exits the system as heat, eventually lost from the atmosphere to space. This simple cycle is actually very complex because so many types of energy transfers happen in so many places.

In the cycle diagrammed above, the energy of the sun is responsible for evaporation of water from surface waters. Water taken up in plants is also lost as vapor and this process is called ‘transpiration’. Together, evaporation and transpiration in the watershed combine to form ‘evapotranspiration’. Precipitation occurs in two primary forms, snow or sleet, and rain – both forms occurring in the Lake Keowee watershed but dominated by rain.

Precipitation that does not evaporate before it reaches the soils of the watershed can be absorbed by those soils thus recharging the groundwater, or it can run off the surface. Normally, if the rate of precipitation exceeds the ability of the soil to absorb the water, the excess is runoff.

Streams carry precipitated water from both surface runoff and from groundwater release. Streams flowing during long times between precipitations are flowing due to releases from groundwater. The variation of stream flow, or discharge as it is often termed, can be plotted graphically. This graph is called a ‘hydrograph’. A typical hydrograph is shown below.



Hydrograph of Single Storm

In this hydrograph are depicted a storm event in the watershed, the base flow due to groundwater discharge, and the rising and falling limbs of the storm hydrograph. The timing and intensity of the hydrographic response to a storm is determined by the intensity of the storm and the characteristics of the watershed. The hydrograph for a watershed that is well-forested and relatively undisturbed will respond more slowly, over a longer time, than for a watershed that contains large area of impervious surfaces such as in urban areas. Impervious surfaces include any land cover that does not absorb water: parking lots, roads, driveways, roofs, etc. In the Lake Keowee watershed, increased construction of impervious surfaces will change the hydrographic response of streams entering the lakes. Increased impervious surfaces will result in quicker hydrographic response and higher peak flows. Such a change would be important for many reasons that will be discussed in later additions to this series.

The next topic will be the sources and transfers of the energy driving this system. The combination of the energy transfers and the water movement set the stage for the most important characteristics of any lake. And for Lake Keowee this is also very true.

Practical Limnology: Energy Basics

By John Hains – Clemson University

Chapter 2

Introduction: In the first installment of this series, I introduced the importance of hydrology to aquatic systems. But while hydrology determines how much water is available and how it is supplied, the hydrologic cycle is driven by inputs and exchanges of energy. This energy, supplied by the sun, drives all natural systems. In fact, we run on this solar energy as well because it is the source of most of the energy for growing our food. But energy is important for lakes and in order to understand energy in lakes, the reader must first understand energy and its interaction with water.

Water is a most wonderful substance. There are no other naturally occurring materials like it. It consists of a single oxygen atom bound to two hydrogen atoms. Similar materials such as methane, ammonia, or hydrogen sulfide are all gases at ‘normal’ room temperatures (approximately 20°C). And except for one factor, water should also remain a gas at ‘normal’ temperatures - indeed the atmosphere does contain gaseous water in vapor form (we call it humidity). But water has a molecular shape responsible for many of the properties we find so wonderful, and that allow it to commonly occur in liquid form at ‘normal’ temperatures.

Water molecules are shaped approximately as shown in figure 1.

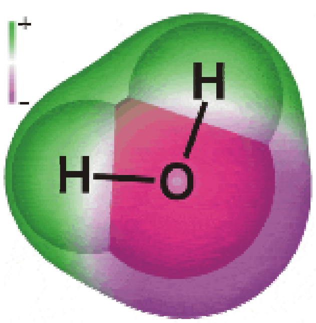


Figure 1. A diagram of a water molecule showing the oxygen atom and two hydrogen atoms bound to it. This diagram and further discussion may be found at: http://www.lsbu.ac.uk/water/molecule.html

Because of the way the water molecule is shaped, the angle between the hydrogen atoms, and the attractive forces between the molecules, water can form a liquid at ‘normal’ temperatures. This is advantageous for those of us who like lakes and, indeed, it is an essential characteristic that allows life to exist. (A very thorough discussion of the water molecule can be found at the referenced web site.)

The attraction between water molecules is the result of ‘hydrogen-bonding’ and this is important because it allows us to understand some of the other properties of this wonderful liquid. Incidentally, we exploit hydrogen bonding every time we warm a cup of coffee in the microwave – the microwave energy interacts with those hydrogen bonds and warms the liquid. And, not surprisingly, other wavelengths of energy are also absorbed by water, many of them supplied from the sun.

The first thing to remember is that not all light is equal. Figure 2 shows an approximate distribution of light energy arriving from the sun.

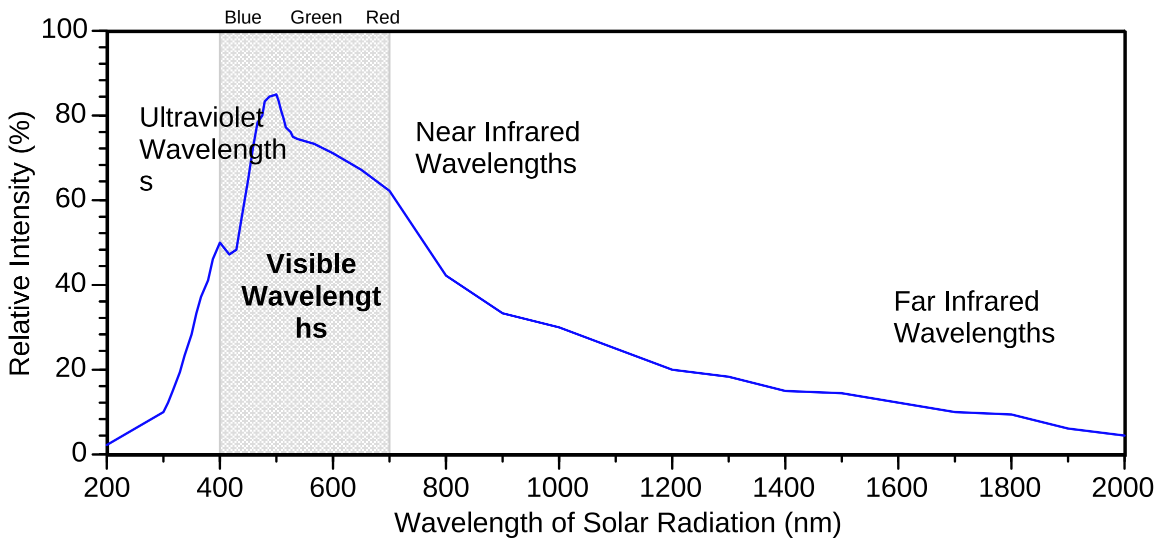


Figure 2. Approximate distribution of solar energy. Note the relative position of ultraviolet and infrared electromagnetic radiation (light).

From the figure it is important to remember that all light is electromagnetic radiation. And also to remember that although electromagnetic radiation (energy) is not always visible it still may be important energy for the lake. But the figure shows that most of the energy of sunlight is associated with wavelengths (colors) that are visible or close to the visible range. In fact, on average, every square meter of the earth receives approximately 350 watts of energy. This conveniently keeps earth at our presently comfortable temperatures – deep space temperature otherwise would be about minus 454°F. Brrr.

But this incoming radiation interacts with water in an interesting manner. Each wavelength (color) is absorbed by pure water differently. That is, water absorbs some wavelengths more strongly than others. In general, longer wavelengths (red ones) are absorbed more strongly by water than shorter wavelengths (blue ones). One consequence of this is that when scuba diving, for example, at greater depths not only is light less intense, it also contains fewer red wavelengths compared to the greens and blues. Underwater photography therefore relies on artificial lighting at greater depths. But the consequence for the lake is happening right now this spring. The sun's energy is being absorbed nearer the surface of the lake and this absorbed energy is warming the water.

Light is important for the energy it brings to the lake and for its support of photosynthesis for phytoplankton and aquatic plants. However, in addition to the basic properties of water, this energy is also affected by other materials dissolved or suspended in the water. Most of us think of this in terms of water clarity. And indeed these dissolved and suspended materials are the subject of measurements taken by lake monitoring teams using secchi disks, who measure the effect of those materials on light penetration into the lake, objective measures of water clarity.

But right now, this spring, the lakes are warming and the energy of the light is interacting with the properties of water to produce the lake characteristics we enjoy for the warmer months. To understand this requires the second installment of this series, immediately.

Practical Limnology: Further Properties of Water and Lakes

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Chapter 3

Introduction: In the second installment of this series, I introduced the importance of energy to water and lakes. In this section I will explain how other properties of water interact with the energy to form the pattern of 'stratification' that we know for our lakes.

By the time you read this, many of you already will have experienced your first sunburn for this season and the growing season will be well underway. Things are warming up. This is true for the lakes as well and the way this happens is the result of the increased energy of the sun (our seasonal cycle) and the way water reacts to that energy.

Everyone knows that in the summer the surface of the lake is warmer than deeper waters. This is another property of water that I have depicted in figure 1.

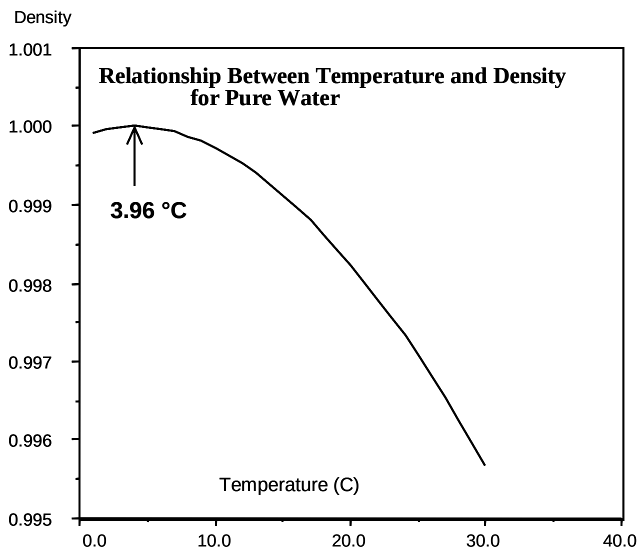

Figure 1. Plot of density versus temperature for temperatures above freezing.

In figure 1, the important trends are that for temperatures normally occurring for Lake Keowee, density decreases as temperature increases. This means that warm water floats over cooler water. Also, the density changes with temperature in a non-linear manner. This is very important for lakes in very warm climates because a small difference in temperature can have an important difference in density.

Another property of water is viscosity. Viscosity is the internal friction of the liquid and we can think of this in terms of liquids we know that are more or less viscous. For example, pancake syrup is more viscous than water – water pours more easily. Honey is so viscous that we nearly have to dip it rather than pour it (mechanics might think about differential lubricant here, or an oil additive such as STP, very viscous). Viscosity is important because warm water is less viscous than cooler water. And this means that warmer water has different flow characteristics from cooler water.

Density and viscosity are both affected by temperature and temperature is mostly affected by the sun's energy. From the second installment of this series, we know that the energy of the sun is absorbed rapidly near the surface of the lake. This is due to the basic property of water but also due to any additional materials that are dissolved or suspended in the lake water. Absorbance of light (energy) tends to increase the temperature of the water. And because most of the energy is absorbed near the surface, most of the increase in temperature occurs near the surface as well. This works well because this warmer water is more buoyant and naturally ‘floats’ above the cooler waters that have not absorbed as much light (energy). However, this tendency for water to form density layers that are different temperatures has another effect. It tends to ‘stratify’ the lake into different limnological layers or zones.

Figure 2 depicts the hypothetical relationship between temperature distribution in a stratified lake as well as the exponential extinction of light in that lake. The temperature distribution is important because the density of water associated with each temperature is different. The less dense water near the surface tends not to mix with waters of greater density at greater depth.

Based on temperature, the stratified lake may be divided into three regions: the Epilimnion or surface layer of the lake, the Hypolimnion or deepest layer of the lake, and the Metalimnion forming the region of transition between the other two layers. These regions are defined by temperature only. And although these layers or zones are often associated with certain chemical trends (especially for oxygen), they are nevertheless strictly defined by temperature.

The epilimnion is the zone in which the warmest (least dense) water resides. Because of convection or wind mixing, the epilimnion often has a minimal temperature (density) gradient associated with it. It is sometimes referred to as the ‘surface mixed layer’.

The metalimnion begins where a strong temperature gradient begins. The term for the strong temperature gradient is the ‘thermocline’. In some views the definition of the thermocline is any temperature gradient that changes at least one degree Celsius in one meter of depth. The depth at which the thermocline is diminished marks the bottom of the metalimnion.

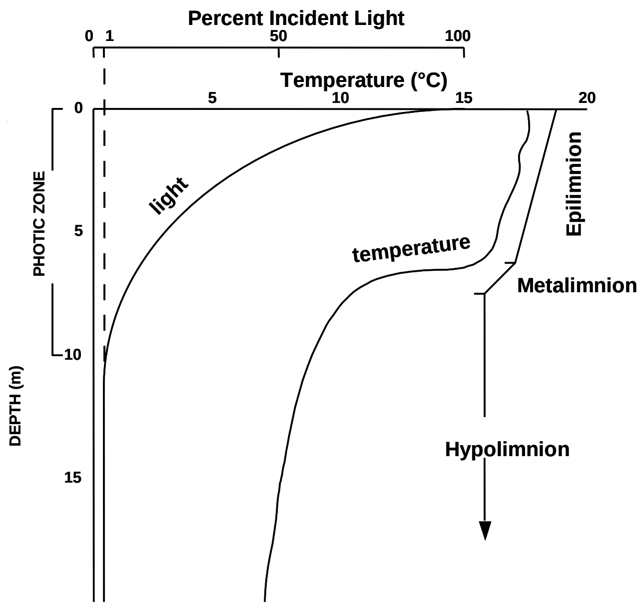

Figure 2. Temperature and light in a stratified lake.

The hypolimnion forms the deepest, coolest (densest) water of the lake. This water is often water that existed during winter and has been isolated from sunlight and the atmosphere by the formation of the less dense, shallower layers. This is very important because the lack of mixing between these layers or zones means that very different water quality can exist or develop during the period of stratification.

Large reservoirs in our region typically have one period of stratification and one season of mixing each year. Such lakes are termed, 'monomictic'. In northern regions lakes (such as Lake Michigan) experience two seasons of mixing, one in the fall and one in the spring. Such lakes are termed, 'dimictic'. And there are a few lakes that never completely mix (Carter's Lake in Georgia is an example) and these are termed, 'meromictic'. More about this another time.

Mixing is important because any type of water movement also requires energy and such movement results in energy exchange. Lake Keowee has several complicating energetic factors that affect the formation of the stratified layers as well as the motions of the water (hydrodynamics) in the lake. These complicating factors include: the operation of hydroelectric facilities at Keowee Dam and Jocassee Dam, the pumping action of Oconee Nuclear Station, and the shape of the basins forming the lakes.

The actions of the hydroelectric facilities and the nuclear station are complex but to understand them, we must first understand the way the shape of the basins affects water movement in the absence of other factors. That will be the subject of the next installment.